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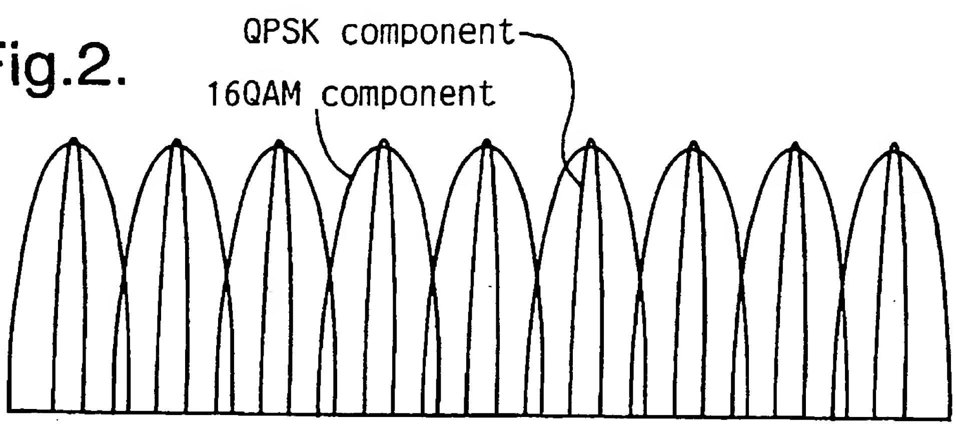
(54) **Signal transmission system**

(57) An improved system for transmitting a coded orthogonal frequency division multiplex (COFDM) signal is proposed wherein bits of data of most importance are coded into portions of the signal with greatest ruggedness, e.g. a QPSK signal. Bits of data of lesser importance are coded onto portions of the signal with less ruggedness, e.g. a 16 QAM signal. The resultant signal is transmitted.

The peak to mean ratio of a signal for transmission is minimised by varying the amplitudes of carriers making up each COFDM symbol from symbol to symbol. At a receiver, (see figure 5), the thresholds for decoding anything higher order than a QPSK signal are computed by averaging the amplitudes of carriers in each quadrant of a phase diagram.

In order to minimise interference to other transmissions the amplitudes of carriers within each symbol are varied such that the interfering contributions from each are equal.

Fig.2.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

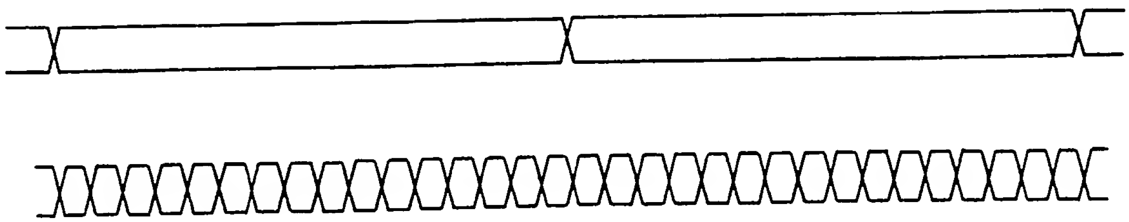


Fig.2.

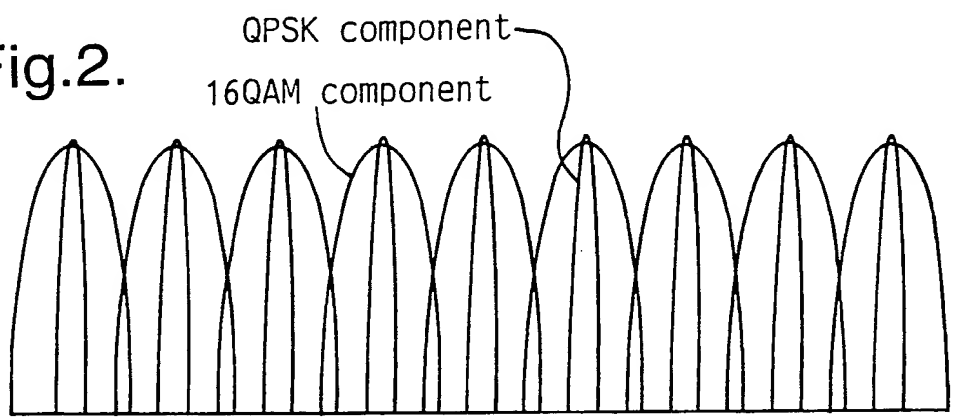


Fig.3.

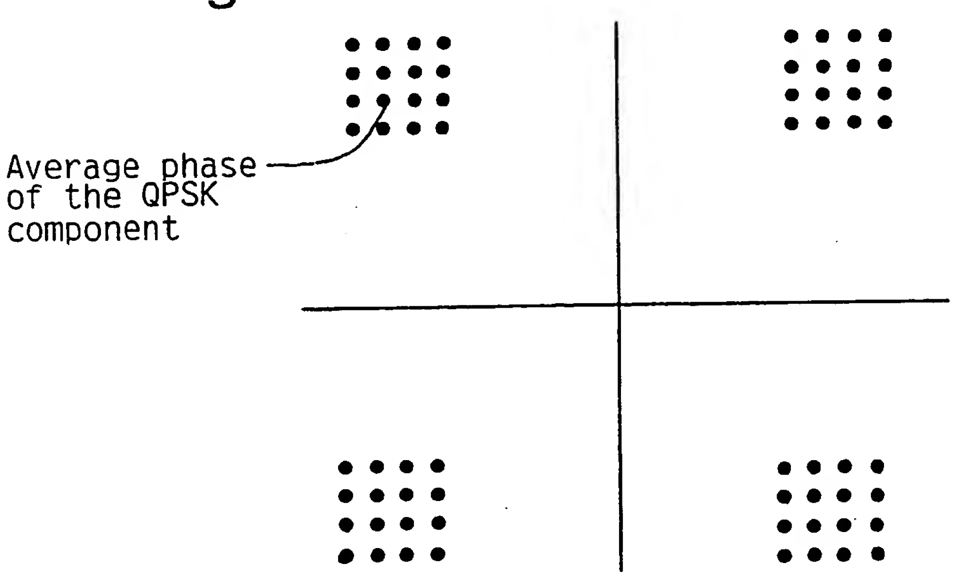


Fig.4a.

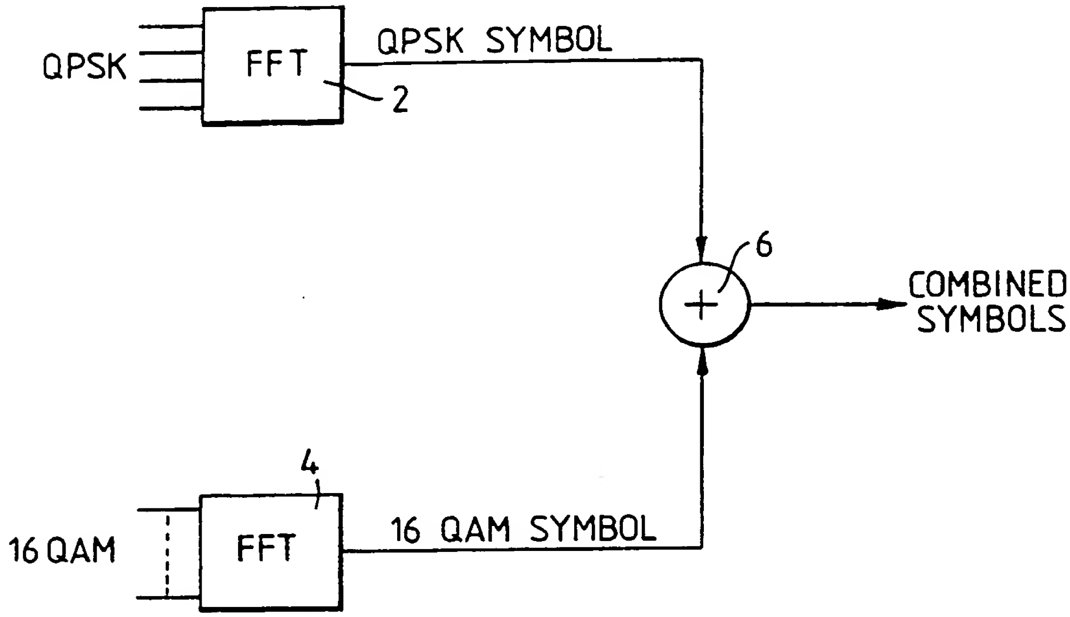

QPSK
FFT
QPSK SYMBOL
2
6
COMBINED SYMBOLS
4
16 QAM
FFT
16 QAM SYMBOL

Fig.4b.

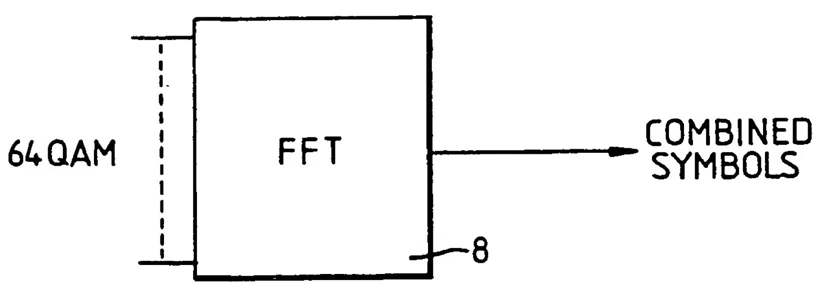
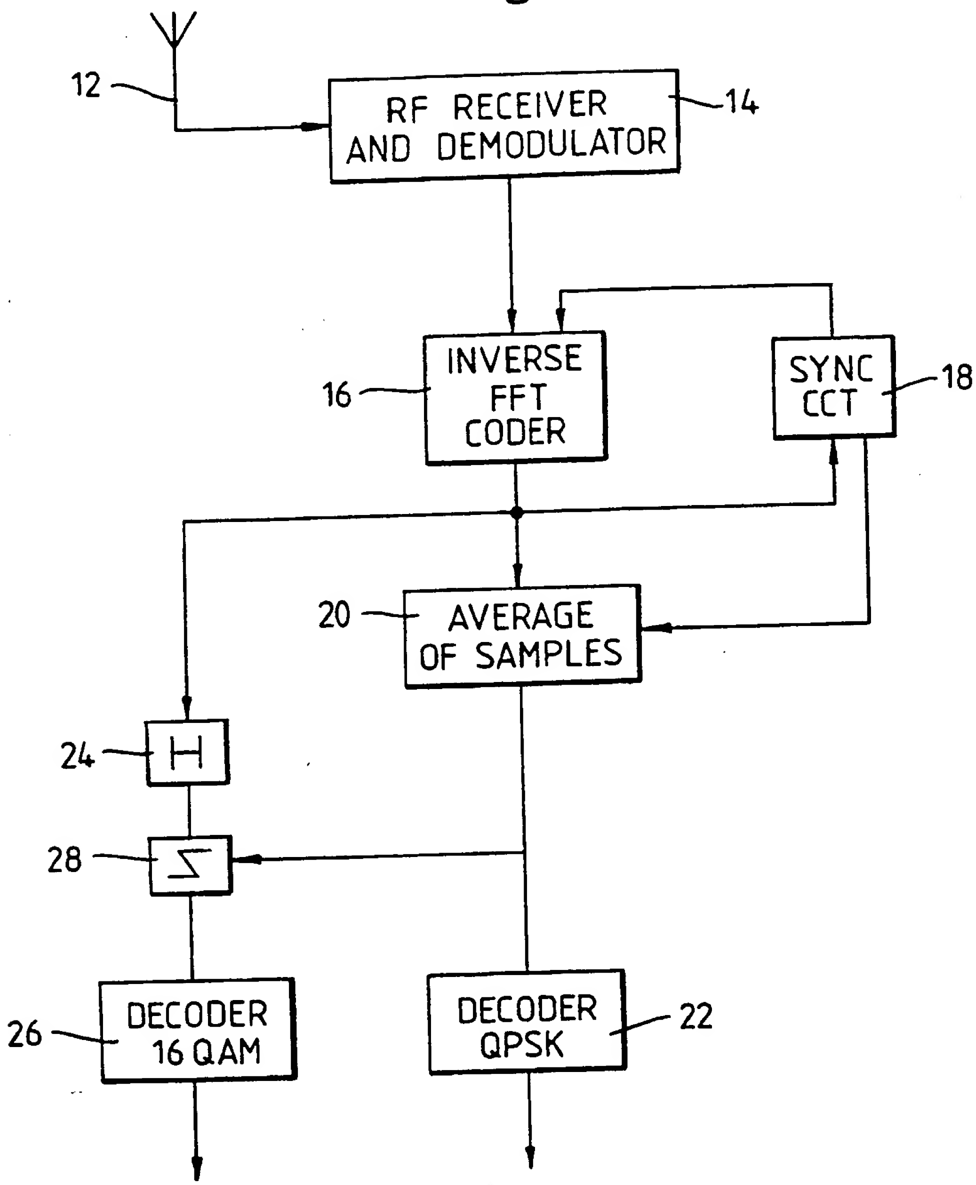

64 QAM
FFT
COMBINED SYMBOLS
8

Fig.5.


12
RF RECEIVER AND DEMODULATOR
14
INVERSE FFT CODER
16
SYNC CCT
18
20
AVERAGE OF SAMPLES
24
H
28
26
DECODER 16 QAM
DECODER QPSK
22

IMPROVEMENTS IN SIGNAL TRANSMISSION SYSTEMS

This invention relates to signal transmission systems in particular to systems which use coded orthogonal frequency division multiplex (COFDM) techniques to transmit digital signals. The invention is particularly applicable to digital terrestrial television broadcasting (dTTb).

COFDM signals are constructed by modulating each of a broad band set of carriers with bits of digital information. This may be done using quadrature phase keying (QPSK), in which case each carrier will be modulated with two bits of digital data or with some higher order form of quadrature amplitude modulation (QAM), for example 64 QAM.

After modulation a fast fourier transform (FFT) of all the carriers is taken to produce a spectrum which is known as a COFDM symbol. Each symbol thus derived is transmitted in the time domain. A transmitted signal will be made up of a stream of these symbols.

At a receiver an inverse FFT of the symbol is taken. This enables the phases of the individual carriers to be realised and thus the digital words which they represent can be reconstructed.

In applying these techniques to dTTb a large amount of data has to be transmitted. We have appreciated that the transmitted signal can be optimised by using a multilevel modulation system of 2 or more QAM systems overlaid. These systems can be arranged to operate at different symbol rates (provided they are integer multiples). For example, a 16 QAM system overlaid on a QPSK system.

A multilevel modulation system such as this will have more ruggedness and an increased guard interval in the lower order modulation levels (the lower the order of the QAM system the greater the inherent ruggedness). This enables the most important data to be transmitted to be assigned to the more rugged modulation system. It is useful in that different receivers will require different quality data. A mobile receiver might only receive rugged important data whilst a high quality receiver would receive all levels of modulation transmitted.

The COFDM techniques summarised above are believed to

be suitable for dTTb as they provide the twin benefits of resistance to impairments caused by multipath distortion in transmission and also allow single frequency network operation. A suitable coding and modulation system for dTTb would be one that allows high data rate, multipath resistance transmission to fixed, directional receiving antennas and lower data-rate, single frequency network operation (which includes multipath resistance) to mobile and portable receivers in the same RF channel. In the latter case a system which is more tolerant to poor carrier to noise ratios (C/N) is necessary.

This invention concerns improvements of signal transmission systems as described below. It is defined in its various aspects, in the appended claims to which reference should now be made.

Embodiments of the invention will now be described in detail with reference to the accompanying drawings in which:

Figure 1 shows the symbol timing of a QPSK component, at the top of the figure, and a 16 QAM component at the bottom of the figure, of a superimposed modulation system embodying the invention;

Figure 2 shows the spectrum of the overall signal;

Figure 3 shows the phase constellation of the overall signal;

Figure 4a and 4b shows alternative embodiments of coding arrangements for use in transmitters embodying the invention;

Figure 5 shows a receiver embodying the invention.

We propose a suitable high frequency system for dTTb in which important data is transmitted with a higher degree of ruggedness than data of lesser importance. This is achieved by transmitting two overlaid OFDM signals.

For example, a 64 QAM signal can be considered as a QPSK signal with a 16 QAM signal modulated on top of it. Such a system is illustrated in the phase diagram of figure 3. As can be seen what is achieved is a distributed 64 QAM system in which each quadrant has a 16 QAM system included in it. A time domain representation of such a system is shown, in QPSK and 16 QAM components in figure 1. It can be seen that the 16 QAM symbol rate is much higher than that the QPSK symbol rate. This makes the QPSK data much more rugged than the 16 QAM data. The

advantage of considering the modulation system as two overlaid lower level systems is that the total symbol periods of the two signals can be very different. This is particularly beneficial in maintaining the orthogonality of the OFDM signals such that mutual interference is prevented. In the overlaid system illustrated it is proposed that all the 16 QAM carriers are used but those in the QPSK signal which would interfere with the 16 QAM should be discarded.

The example shown in figure 1 is of a QPSK signal with a total symbol period 16 times longer than that of the 16 QAM signal.

In order to produce the two overlaid signals two possibilities are proposed and these are shown in figures 4a and 4b. Figure 4a shows QPSK and 16 QAM being input to separate FFT coders 2 and 4 which will respectively produce the symbol outputs illustrated in figure 1. These symbols are then combined in adder 6 the output of which can then be transmitted in the time domain.

Figure 4b shows a different arrangement in which the data is combined in the frequency domain and effectively treated as a 64 QAM signal which forms the input to a single FFT coder 8. In this arrangement the more important data will be used to determine which quadrant of the phase diagram the carrier is to fall within and the 16 QAM data is then superimposed on top of that with data of lesser importance. The differential symbol rate of the QPSK and 16 QAM systems is maintained by assigning a single QPSK state to, for example, 16 of the carriers and then superimposing the 16 QAM data on each of these.

As is known guard intervals can be used with QPSK symbols. These are used to clearly delineate the start and end of a symbol. When a guard interval is used it comprises, at the end of a symbol, a repeated portion of data (the FFT output) from the start of the symbol. This leads to greater ruggedness in the system and aids synchronisation. In the present system a guard interval could be included in the QPSK symbol but not in the overlaid 16 QAM symbol. This is because the QPSK data is more important, more rugged, and thus easier to demodulate.

On the face of it an overlaid signal such as this would appear to be difficult to demodulate. However, a possible approach can be seen by considering the problem in the time

domain. When the QPSK signal is demodulated by the "integrate and dump" in the FFT in a decoder the effect of the 16 QAM signal will be averaged out and the theoretical performance of the QPSK signal can be derived for each component. Further coding can be added to ensure that over the 16 symbol periods of the 16 QAM signal, the average amplitude of the 16 QAM modulation was zero. Without such a coding, degradation from the theoretical performance of QPSK would result.

Alternatively the 16 QAM signal could be modulated using a separate FFT after the central slicing level of the output of the FFT has been determined as the average result from QPSK demodulation, i.e. the thresholds for 16 QAM demodulation are set in dependence on the average QPSK levels.

A block diagram of a possible receiver is illustrated in figure 5. In this a signal from a transmitter is received on an antenna 12 which provides a signal to the analogue part of the RF receiver and demodulator 14. The output of this forms the input to an inverse FFT coder which will convert back from the time domain to the frequency domain. This coder 16 has to be synchronised to the symbol periods received. This is achieved by analysing the output in a synchronising circuit 18 and using this to control the coder 16.

When the coder has been synchronised a sample averager 20 receives groups of 16 samples, takes their average, and provides an average output which represents the QPSK data. This is decoded in a QPSK decoder 22.

The data also passes to a delay 24 which delays it by the same amount as the sample averager 20 delays the QPSK data from where it can pass to a 16 QAM decoder 26 via a threshold level setter 28. This sets the 16 QAM slicing levels for demodulation in dependence on the QPSK levels computed by the averager 20.

Thus it can be seen the sample averager determines the QPSK data whilst the 16 QAM data can be analysed in dependence on the QPSK levels.

In transmission the relative amplitudes of the QPSK and 16 QAM components can be adjusted to achieve the desired relative performance in a noisy channel. It is assumed (and probably necessary) that QPSK component is significantly more rugged than the 16 QAM component as the former is required to

cover the latter. The system itself, however, already favours the QPSK signal quite significantly. The inherent performance of the QPSK signal is approximately 6 dB better than the 16 QAM signal and QPSK symbols are transmitted for 16 times longer than the 16 QAM symbols. This gives a 12 dB benefit. The difference in performance of the components would be more than 18 dB even when their relative amplitudes are the same.

The effect of this overlaid transmission approach on the spectrum efficiency in multipath resistance of the system is of note. The use of OFDM systems means that the theoretical spectrum efficiency of each system is given by the spectrum efficiency of the underlying modulation system - assuming that the ratio of guard interval to total symbol rates are the same in each case. However, as the total symbol rates are different the guard intervals, if used, will be different. As a result the different components should be able to tolerate different delays of multipath distortion. The guard interval lengths can be arranged to allow single frequency network operation with the QPSK component (which would carry a low data rate, and relatively high code rate signal) and to provide only multipath immunity from a single transmitter for the 16 QAM component (which would carry the high data rate, low code rate signal).

The effect of phase noise on these systems is somewhat unclear. It would be expected that the QPSK components would be more susceptible to phase noise due to the low symbol rate, but more rugged due to the inherent ruggedness of the modulation system. The individual systems can be designed to minimise the effect of phase noise, for example, QPSK component can use differential demodulation systems. Individual systems can be designed to minimise the effect of phase noise, for example a QPSK component can use differential demodulation and the 16 QAM component can use coherent demodulation. This system has the disadvantage of reducing the data capacity in the QPSK component. For example, a system with a factor of 16 differentiation between the symbol rates would loose 15/16ths capacity on the QPSK component but would benefit from a 12dB increase in minimum signal strength. Thus it will be appreciated that compared with conventional 64 QAM system data capacity has been traded for an increase ruggedness of some of the data bits.

The overlaid system has been described in the context of a superimposed OFDM modulation system but the ideas are applicable more generally to superimposed modulation schemes generally on one or more carriers. The system may be used for dTTb transmissions or for any other digital transmission which it is desired to make.

We have also appreciated that a major disadvantage of OFDM systems is that the ruggedness of a signal in the presence of multipath distortion has been obtained at the expense of choosing a signal which requires linear amplifiers with a large amount of head room. The linearity requirement is not particularly stringent, compared with analogue TV systems, but the larger amount of headroom required to prevent unwanted intermodulation products from being generated will make broadcast transmitters very expensive.

It is therefore desirable to identify methods of conditioning the OFDM signal to reduce its peak to mean ratio. One of the methods proposed for digital audio broadcasts (DAB) allows the amplitude of each QPSK carrier to change slightly with each symbol. The changes are so arranged to reduce the size of large peaks in the overall signal. The problem of applying the approach to a higher order modulation system such as 64 QAM is that the threshold levels between the multilevel states must be known. The variation in carrier amplitudes moves the points in the constellation but the demodulator has no way of knowing that the threshold levels must be changed.

The proposed method can be used in a system such as the one described above and has been suggested for the receiver shown in figure 5. As the signal is the superposition of two signals, one of which is a QPSK signal, the amplitude of the QPSK components on each carrier can be adjusted from one QPSK symbol to the next. This should reduce the peak to mean ratio of the overall signal. The signal superimposed on the QPSK signal is the 16 QAM component. The central threshold of this can be taken from the amplitude of the QPSK component which is derived by taking an average of 16 components falling within any quadrant of the phase diagram. Derivation of this central threshold of the 16 QAM component enables the 16 QAM levels around this to be derived. Any variation in the central threshold should not have any material effect on the

demodulation of the 16 QAM component.

If the second component were a QPSK signal as well, then further control of the peak to mean ratio may be possible by allowing the instantaneous amplitude of the high symbol rate component to vary between symbols. However, the restriction would remain that the average carrier amplitude over the low symbol period should be arranged to zero. In fact, the algorithm would have to be more complicated than this as the margin of the QPSK signal should not be degraded but may be enhanced. However, any enhancement would increase the transmitted power and so some limits on this would be required. Finally the presence of the guard interval on the QPSK component means that not all of it is demodulated. Therefore, the algorithm would have to ensure that a significant degradation of the QPSK component did not occur over the possible range of positions of the FFT window.

It has been suggested that the amplitudes of OFDM carriers could be arranged to produce favourable protection ratios with other, co-channel OFDM multiplexes.

It has also been shown that the effect of co-channel interference to OFDM systems from conventional analogue television systems can be substantially reduced (at least in the absence of error correction) by removing a number of the most interfered with carriers.

Optimum protection ratios for co-channel interference for OFDM systems into conventional analogue television systems could be obtained by suitable adjustment of the amplitudes of the OFDM carriers. That is to say that to minimise interference to existing users of a channel, the amplitudes of the individual carriers in an OFDM system should be arranged so that the interfering contribution from each is equal. The optimum levels may ge given by the relative changes with frequency of the CCIR protection ratio curves for interference of television systems from CW interferers.

It will be appreciated by those skilled in the art that the ideas discussed above can be implemented in dedicated hardware circuitry or, alternatively in software using well known techniques.

CLAIMS

1. A method of transmitting a coded orthogonal frequency division multiplex (COFDM) signal comprising the steps of coding portions of the signal with greatest resistance to distortion with the most important bits of data and portions of the signal with lesser resistance to distortion with bits of data of lesser importance, and transmitting the resultant signal.

2. A method of transmitting COFDM signal according to claim 1 in which the coding steps comprise coding a first quadrature amplitude modulation (QAM) signal with the bits of data of most importance, coding at least one higher order QAM signal with the bits of data of lesser importance, and combining the resultant signals to produce a single signal for transmission.

3. A method of transmitting a COFDM signal according to claim 1 in which carriers in the first QAM signal are discarded if they interfere with any carriers in the higher order QAM signal.

4. A method of transmitting a COFDM signal according to any preceding claim in which the first QAM signal comprises a quadrature phase shift keying (QPSK) signal.

5. A method of transmitting a COFDM signal according to any preceding claim in which the symbol period of the first QAM signal is an integer multiple of the symbol period of the higher order QAM signal.

6. A method of transmitting a COFDM signal according to any preceding claim including the step of varying the amplitudes of carriers forming each symbol in the first QAM signal from symbol to symbol thereby reducing the peak to mean ratio of the resultant signal.

7. A method of transmitting a COFDM signal according to any preceding claim including the step of varying the amplitudes of individual carriers forming the COFDM signal such that the

interfering contribution from each carrier to other transmissions is substantially equal to the interfering contribution from each other carrier.

8. Apparatus for transmitting a COFDM signal comprising means for coding portions of the signal with greatest resistance to distortion with bits of data of most importance and means for coding portions of the signal with lesser resistance to distortion with bits of data of lesser importance and means for transmitting the resultant signal.

9. Apparatus for transmitting a COFDM signal according to claim 8 in which the coding means comprises means for coding a first QAM signal with the most important bits of data, means for coding at least one higher order QAM signal with the bits of data of lesser importance and means for combining the resultant signals for transmission.

10. Apparatus for transmitting a COFDM signal according to claim 9 in which carriers in the first QAM signal are discarded if they interfere with carriers in any higher order QAM signal.

11. Apparatus for transmitting a COFDM signal according to claim 10 in which the first QAM signal comprises a QPSK signal.

12. Apparatus for transmitting a COFDM signal according to any of claims 8 to 11 in which the symbol period of the first QAM signal is an integer multiple of the symbol period of the higher order QAM signal.

13. Apparatus for transmitting COFDM signal according to any of claims 8 to 12 including means for varying the amplitudes of carriers forming each symbol in the first QAM signal from symbol to symbol thereby reducing the peak to mean ratio of the resultant signal.

14. A method for receiving a signal formed from at least two overlaid QAM signals each carrying different bits of data,

the method comprising the steps of repeatedly taking an inverse Fast Fourier Transfer (FFT) of portions of the received signal, analysing the resultant carriers, synchronising the inverse FFT in dependence on the result of the analysis, separating the carriers from the two QAM signals and analysing the phases of the carriers to determine the bits of data carried by them.

15. A method for receiving a signal formed from at least two overlaid QAM signals each carrying different bits of data, according to claim 14 in which a first QAM signal comprises a QPSK signal and a second QAM signal comprises a higher coder QAM signal, the analysing step comprises averaging carriers received in each quadrant of a phase diagram to determine the data carried by the QPSK signal, and further comprising setting a threshold level for analysis of the higher order QAM signal in each quadrant in dependence on the result of the averaging step.

16. Apparatus for receiving a signal formed from at least two overlaid COFDM QAM signals each carrying different bits of data comprising inverse Fast Fourier Transfer (FFT) means for operating on the received signal, means for analysing the resultant carriers, means for synchronising the inverse FFT means in dependence on the result of the analysis, means for separating the carriers of the two QAM signals and means for analysing the phases of the carriers to determine the bits of data carried by them.

17. Apparatus for receiving a signal formed from at least two overlaid COFDM QAM signals each carrying different bits of data according to claim 16 in which a first QAM signal comprises a QPSK signal and a second QAM signal comprises a higher order QAM signal, the analysing means comprises means for averaging carriers received in each quadrant of a phase diagram to determine the QPSK data, and further comprising means for setting threshold levels for analysis of the higher order QAM signal in each quadrant in dependence on the result of the averager.

18. A method for reducing the peak to mean ratio of a COFDM signal comprising the step of varying the amplitudes of

carriers forming each symbol in the signal from symbol to symbol.

19. A method of minimising the interference from a COFDM signal to other transmissions comprising the step of varying the amplitudes of individual carriers forming the COFDM signal such that the interfering contribution from each carrier is substantially equal to the interfering contribution from each other carrier.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

-12-

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Search Examiner	MR S J L REES
Date of completion of Search	27 OCTOBER 1994
Documents considered relevant following a search in respect of Claims :-	1-13

Relevant Technical Fields

(i) UK Cl (Ed.M) H4M (ME, MFX) H4P (PDX, PEE)

(ii) Int Cl (Ed.5) H04J (1/02, 9/00, 11/00, 13/00) H04L (5/00, 5/06, 27/00)

Databases (see below)
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E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X,&	EP 0448492 A1	(ETAT FRANCAIS) Figure 1 and WPI Abstract Accession No 91-283461/39	1, 2, 4, 5, 8, 9, 11, 12
X,P	US 5243629	(AT & T) whole document especially lines 43 to 58 of column 2	1, 2, 5, 8, 9, 12
X,&	US 5197061	(ETAT FRANCAIS) whole document especially lines 54 to 62 of column 2	1, 2, 4, 5, 8, 9, 11, 12

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